

REMARKS

This paper responds to the Office Action dated December 3, 2001.

Claims 1-36 were pending at the time of the Office Action. Claims 1-36 have been canceled and new claims 37-71 have been added. The new claims correspond roughly with the old claims as follows:

old	1, 9	2	3	4	5	6	7	8	10
new	37	38	39	40	41	42	43	44	45

old	11	12	13	14	15	16	17	18	19
new	46	47	48	49	50	51	52	53	54

old	20	21	22, 9	23	24	25	26	27	28
new	55	56	57	58	59	60	61	62	63

old	29	30	31	32	33	34	35	1, 9, 36
new	64	65	66	67	68	69	70	71

Claim Rejections 35 USC §112

Claims 16 and 27. The Examiner rejected claims 16 and 27 as supposedly indefinite. The Examiner stated that he was unclear as to the structure used for cavity dumping.

It is respectfully suggested that "cavity dumping" is a method of coupling out radiation from a laser cavity. An acousto-optic device is suddenly switched on, by which a beam path out of the cavity is provided, so that energy is nearly instantly dumped from the laser cavity. It is further respectfully suggested that "cavity dumping" has a definite and well-known meaning in the art.

5 Attached please find a copy of an extract from a standard solid-state laser textbook, namely W. Koechner, Solid-State Laser Engineering, 5th ed., (Springer-Verlag, Berlin, 1999). In the extract, cavity dumping is explained,

Reconsideration of the rejection of claims 16 and 27 is thus respectfully requested.

10 **Claim 36.** The Examiner rejected claim 36 as supposedly indefinite, being a method claim depending from an apparatus claim (claim 1). New claim 71 has been introduced which is intended to correspond with former claim 36, incorporating limitations from former claims 1 and 9. Claim 71 does not depend from any other claim.

Claim Rejections 35 USC §103

15 The former independent claims were claims 1, 22, and 36. New independent claims 37, 57, and 71 are now present. Each of these claims incorporates the subject matter of former claim 9.

20 In the office action, the Examiner stated that the subject matter of the former claims 1 and 22 as well as of some dependent claims was made obvious over Kasamatsu et al. (Applied Optics, Laser-Diode-pumped Nd:YAG active mirror laser, "Kasamatsu") and Weingarten et al. US Pat. No. 5,987,049 ("Weingarten"). It is respectfully suggested that the subject matter of the new independent claims is not made obvious by the cited references.

Kasamatsu shows a thin-disk laser, the thin-disk laser medium being mounted on a cooling surface. However, Kasamatsu shows a *continuous-wave* (cw) laser (see page 1879, second column), and *not a laser for emitting pulsed electromagnetic radiation* as in the claimed

preamble

invention.

The requirements for continuous-wave lasers differ in many aspects from the requirements for of pulsed lasers. Whereas the cavity of cw lasers is designed to provide a monochromatic, coherent output beam, in pulse-generating lasers the cavity has to be designed to optimize the pulse
5 duration (i.e. to provide short pulses) and/or the repetition rate. For example, in mode-locked lasers, the cavity lengths directly defines the pulse repetition rate. This means that in order to obtain the desired high pulse intensity, the cavity has to be of a much greater size for pulse generating lasers than for the laser of Kasamatsu. More generally, there are fewer degrees of freedom available to the designers of pulse-generating lasers.

10 For these reasons, cw lasers and pulse-generating lasers are completely different fields, in which different search groups are active, which concern different laser manufacturing industries etc. For example, the assignee of this application is a manufacturer of pulse generating lasers and would not have the know-how for fabricating a competitive cw laser. The expert in the field of pulse-generating lasers would thus never consider the Kasamatsu reference. However, even if we were
15 to assume for sake of discussion that he would, the following comments would apply.

The examiner correctly points out that Weingarten discloses a semiconductor saturable absorber mirror (SESAM) for passive mode locking of a resonator. However, the laser shown by Weingarten is merely a low average output power pulse generating laser.

20 In fact, SESAMs as such have been known in the art for several years now. However, the expert has *no motivation whatsoever* to introduce such a SESAM into the laser device of Kasamatsu. SESAMs are exclusively useful for mode-locking in pulsed lasers. Introduced in a cw laser such as Kasamatsu's, they would inevitably render the laser unusable. None of the cavity design parameters would be suited for a pulse generating laser (see the description by Kasamatsu on pages 1879-1880). Additionally, SESAMs bring about losses (saturable and non-saturable
25 losses). They also are delicate parts which tend to be thermally damaged quite easily.

Compared to the teaching of Kasamatsu, a cavity for a *pulse generating laser* would have to be redesigned from scratch in order to function properly.

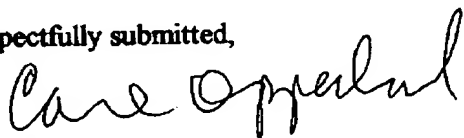
More generally, the expert will *not consider* introducing a saturable absorber in a high average output power laser such as a cooled-thin-disk-laser. The reasons for this are set out on page 4 of the specification of the present application. They are also described in the German patent application publication DE19907722, mentioned at page 4 of the specification. Lines 17-30 of Column 2 of this publication translate as follows:

For laser systems with high power (some 100mW) and on another basis (cf. e.g. EP0492944A2) a method for passively mode locking by means of a Kerr lens device was provided, wherein no hints towards an application in high power laser systems with ultra-short pulses can be found, though. Rather, further progress has been achieved using semiconductor based saturable absorbers (SESAMs), which, however, have proven to be too short-lived for high power laser systems, regarding their applicability for powers above some 100mW. On the other hand, non-linear optical methods are preferred, since they are power scaleable by means of appropriate focussing of the beam, and since they do not rely on direct absorption of radiation.

It is an *achievement* of this invention as defined in the independent claims to have *considered and reduced to practice* introducing saturable absorbers into a laser with a laser gain medium having two end faces, and at least one of said end faces comprising a cooling surface, i.e. a laser being designed for high power operation.

For all these reasons, reconsideration is requested.

Respectfully submitted,



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P. 12

Walter Koechner

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|---|--|---|--|---|--|---|---|--|---|--|--|--|---|--|--|--|
| 42 Principles of Phase Conjugation
By R. Y. Chiao, R. E. Dieder, R. E. Fickler,
and V. V. Shkunov | 60 Holographic Interferometry
In Experimental Mechanics
By Y. L. Chao, V. P. Shchegolev,
and V. V. Tsvetkov | 61 Mathematics and Simulation of Waveguide
Lasers: A Handbook of Laser Mathematics
By R. G. Chang | 62 Photoacoustics
And Photoacoustic Phenomena II
Editors: J. C. Berg, A. W. Maichle, R. E. Dieder,
L. C. Aulic, and D. R. K. Rogers | 63 Spectroscopic Laser Spectroscopy
By R. G. Chang | 64 Spectroscopy of High-Pressure
By R. G. Chang | 65 Spectroscopy of High-Pressure Optical Crystals
By V. S. Zolotarev, G. G. Chiriac,
and R. N. Nigmatov | 66 High-Speed Dye Lasers
Editor: P. J. D'Amico | 67 Solid-State Resonating Materials
For Holography and Thin-Film Processing
By R. J. D'Amico | 68 X-Ray Microscopy III
Editors: A. G. Anderson, G. R. Morrison,
and C. J. Ruck | 69 X-Ray Microscopy
Principles and Methods
Editor: T. M. Kozicki | 70 Photoacoustics
And Photoacoustic Phenomena III
Editor: D. Maichle | 71 Electron Microscopy
By A. Tsvetkov | 72 Spectroscopy of Energy-Relaxing
Transitions in Electron Microscopy
Editor: L. K. Shcherbakov | 73 Handbook of Thin-Film Optical Effects
And Effects
Editor: T. Otsu | 74 Spectroscopy of Thin-Film
By P. J. D'Amico | 75 Interferential Effects in Optics
And Photoacoustics: ICD IV
Editor: T. Otsu |
|---|--|---|--|---|--|---|---|--|---|--|--|--|---|--|--|--|

Volumes 1-41 are listed at the end of the book

20-FEB-2002 WED 15:51

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P. 13

34 1. Q-switching

to be converted by means of a parametric oscillator or Raman cell (Chap. 10). An alternative approach for optical amplifiers is based on flashlamp or diode pumped Br. glass lasers which directly emit at the desired wavelength. The most popular method of Q-switching such lasers is the rotating Pockels prism. However, recently, passive Q-switches based on medium doped QW, have been developed for this laser (8.87.48).

8.6 Cavity Dumping

A means for generating extremely short Q-switched laser pulses involves Q-switching the laser with 100% mirrors on both ends of the cavity and then, at the peak of the circulating power, rapidly switching the output mirror from 100% to 0% reflectivity. This leads to a rapid dumping of the entire optical energy from within the cavity. One of the advantages of this technique is the production of Q-switched pulses whose width is primarily a function of the oscillator cavity length, rather than the gain characteristics of the laser medium. Specifically, the laser pulse width at the half-power points will be equivalent to the round-trip transit time in the cavity, with the condition that the Q-switch employed has switched within this same time period. Thus, based on allowable cavity dimensions, pulse widths in the range of 2 to 5 ns are feasible for oscillators whose pulse widths are of the order of 10 to 20 ns in the normal Q-switch mode.

Figure 8.31 shows the optical layout of a ruby oscillator employed to generate short pulses by the cavity dumping mode. We will explore the operation of the system by assuming that the ruby c plane is perpendicular to the plane of the paper. When the flashlamp is fired, the horizontally polarized ruby fluorescence is transmitted by the thin-film or calcite polarizer, thereby preventing regeneration. Upon reaching peak-energy storage in the ruby, the Pockels cell is biased to its half-wave retardation voltage. The resulting vertically polarized light is reflected by the polarizer to the off-axis mirror, and regeneration occurs in the cavity. When the power in the cavity reaches its peak value, the bias is removed from the Pockels cell in a time period of about 2 ns. The cavity energy then liberally drains out of the cavity in the time required for the reflection to travel one round trip in the optical cavity. The combination of the polarizer, Pockels cell, and 100% mirror comprises what amounts to a high-speed voltage-variable mirror whose reflectivity is changed from 0 during the pumping cycle to 100% during the pulse buildup, and back to 0 during the cavity dumping phase.

To illustrate the practical realization of this technique, we will consider a typical ruby oscillator consisting of a 10-cm by 1-cm ruby rod, a Pockels cell, a thin-film polarizer, and two 99% mirrors. If we assume a 75-cm-long cavity, we obtain a round-trip transit time of 5 ns. The ruby rod is pumped by a 1-msec-long flashlamp pulse, and the Pockels cell is switched the first time after about 0.8 ns. The short delay between switching the Pockels cell and the occurrence of peak power in the cavity is typically 60 ns. In order to extract the stored cavity energy,

8.6 Cavity Dumping 315

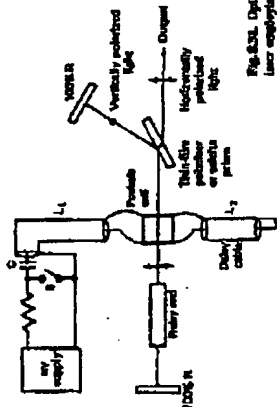


Fig. 8.31. Optical layout of a ruby laser employing cavity dumping.

the bias on the Pockels cell is returned to zero after this time delay. This can be accomplished by means of the circuit shown in Fig. 8.31. In this arrangement, the Pockels cell is connected in-line between coupled inductors L_1 and L_2 . Closing the switch S will discharge the capacitor C into the transmission line L_1 . When the voltage pulse reaches the Pockels cell, the optical beam will experience a 90° polarization rotation and the Q-switch pulse will start to build up from noise. Assuming a perfect 50 Ω impedance of the Pockels cell, no reflection will occur at the cell and the voltage pulse will travel to the end of the stored transmission line L_2 . At that point the pulse will be reflected with a 180° phase shift. When the reflection reaches the cell, the voltage on the crystal will be zero. Therefore the length of cable L_2 determines for how long the voltage is applied to the Pockels cell.

The performance of a ruby oscillator having the above-mentioned system parameters is illustrated in Fig. 8.32. Shown is the power inside the resonator if the energy is not dumped (Fig. 8.32a). The measurement was made by monitoring the leakage radiation through one of the 99% mirrors with a fast detector and oscilloscope. The peak power and energy inside the resonator were determined to be 190 MW and 1 J, respectively. Figure 8.32b depicts the circulating power monitored through the same mirror if the energy is dumped and the system is operated as a PDM oscillator. The biased cavity power reaches almost the same value as in Fig. 8.32a, then falls in about 5 ns to almost zero. This reveals that all but a small percentage of the available energy has been dumped from the cavity. Figure 8.32c reveals that the dumped pulse is triangular, with a 10 ns 90% rise time of 3.0 ns and a pulse width of 5.5 ns. This width compares exactly with the cavity round-trip transit time within experimental error. The total energy of this pulse was measured to be 0.75 J. The peak power of this pulse is thus 1.4×10^8 W. The rise time of the output pulse is determined by the switching speed of the hydrogen dynodes which was used to discharge capacitor C . The experimental data reveals that 15% of the stored energy was extracted from the resonator.

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P. 15

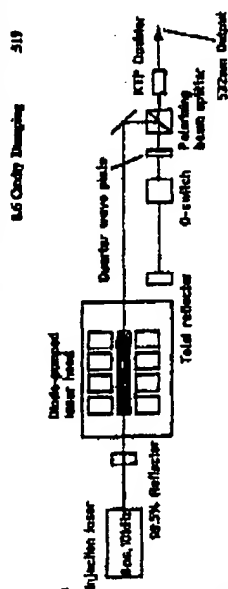
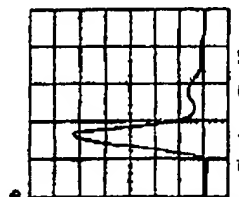


Fig. 8.34a,b. Cavity dumping of an injection seeded laser. Optical schematic of laser system (a) and output pulse shape (b).



operated at zero wave retardation. This is the low Q-condition because radiation is transmitted out of the resonator through the polarizers. At the end of the pump pulse, the injection laser sends a 6 ns pulse into the resonator through the rear reflector. At the same time, the Pockels cell is switched to 1/4 wave retardation which establishes the high Q-condition. Radiation is building up between the two highly reflective mirrors. The injected pulse is repetitively amplified in the cavity for about 360 ns or 120 passes. The Q-switch is then returned to zero wave retardation which dumps the amplified pulse through the polarizer. The KTP crystal converts the wavelength to 532 nm and shortens the pulse to about 5 ns. The response is repeated at a 10 kHz pulse repetition frequency. Figure 8.34b displays the output pulse at 532 nm.

An analysis of the connection efficiency of cavity-dumped regenerative lasers can be found in [8.104]. The results are quite similar to the Q-switched case, and the extraction efficiency depends only on the amplifier gain and resonator losses.

5.8 Q-switching

formed by three high-reflectivity mirrors M_1 , M_2 , and M_3 . The mirror curvatures and the distances between M_2 and M_3 are chosen such that the light beam between M_2 and M_3 is focused to a small diameter at the center of curvature of M_1 . The modulator is inserted at the waist of the optical beam.

Acousto-optic modulators employed for cavity dumping differ from their counterparts used in Q-switch applications in several respects:

- 1) Compared to Q-switching, the cavity-dump mode requires much faster switching speeds. The rise time in an acousto-optic modulator is approximately given by the beam diameter divided by the velocity of the acoustic wave. In order to obtain rise times around 5 ns, a value which is required for efficient cavity dumping, the incident beam must be focused to a diameter of approximately 50 μm .
- 2) For efficient operation in the cavity-dump mode, it is important that essentially all the circulating power be diffracted into the first diffraction order. In a Bragg device the diffraction efficiency increases with the if carrier frequency, therefore modulators employed in cavity dumpers operate at considerably higher frequencies, i.e., 200 to 500 MHz as compared to acousto-optic Q-switches.
- 3) In order to generate an output pulse in the cavity-dump mode, a short if pulse is applied to the modulator, whereas in an acousto-optic Q-switch the if carrier is turned off for the generation of an output pulse.
- 4) The cavity is never kept below threshold conditions as in the Q-switched mode of operation. If the cavity is dumped of all its energy, the field has to build itself from the noise level. Repetitive cavity dumping was observed to become unstable in this case. If the repetition rate is lowered, the laser material is pumped higher above threshold between pulses, therefore, a larger fraction of the stored energy is extracted from the system (see Sect. 8.1). The lower limit of the dumping repetition rate is reached when the internal laser energy decreases to one photon immediately after dumping. The upper limit of the cavity dumping repetition rate is set by the switching speed of the modulator. Repetition rates as high as 10 MHz have been reported. From a cw-pumped Nd:YAG laser capable of 10 W of raw power, peak powers of 570 W with a pulse duration of 25 ns have been obtained at a 2 MHz repetition rate [8.100]. For high-data-rate communications systems, cavity dumping of cw-pumped lasers is sometimes combined with mode locking [8.101, 102].

The technique of cavity dumping is also employed in regenerative systems. In a regenerative laser a pulse is injected into a laser resonator containing an amplifier. The pulse passes several times through the same amplifier medium and is then switched out. Figure 8.34a shows an optical schematic of a laser which employs this technique [8.103]. Illustrated is a double-pumped Nd:YAG crystal located between two highly reflective mirrors, a Pockels cell Q-switch and a polarizer. The Nd:YAG crystal is cw-pumped and repetitively cavity dumped at a 10 kHz repetition rate. During the 100 ns pump time, the Pockels cell is